GENIE Developments

1. Intranuclear Rescattering Model
2. Cross Section Model Retuning
3. Validation
4. np-nh Scattering Mechanisms

H. Gallagher

NoVA Meeting

Apr. 19, 2012

Basic outline

S. Dytman
NuINT 2011

Hadron in nucleus
produced at a principal vertex
(e.g. pion production)

Formation time = **Free step**
Step hadron through nucleus in 0.1 Fm steps. Assess probability of interaction with $\lambda(E,r)=1/\rho(r)\sigma(E)$.

default

hA model
- Choose interaction from list (data, models, intuition)
- Elas, Inel, CEX, abs (KO), pi prod
- Choose kinematics by models, phase space and exit.

hN model
- Choose interaction according to list (data, models, intuition)
- Elas, CEX, π prod, abs, pre-eq
- Choose kinematics by PWA model
- Add particles to stack until all out.

General characteristics

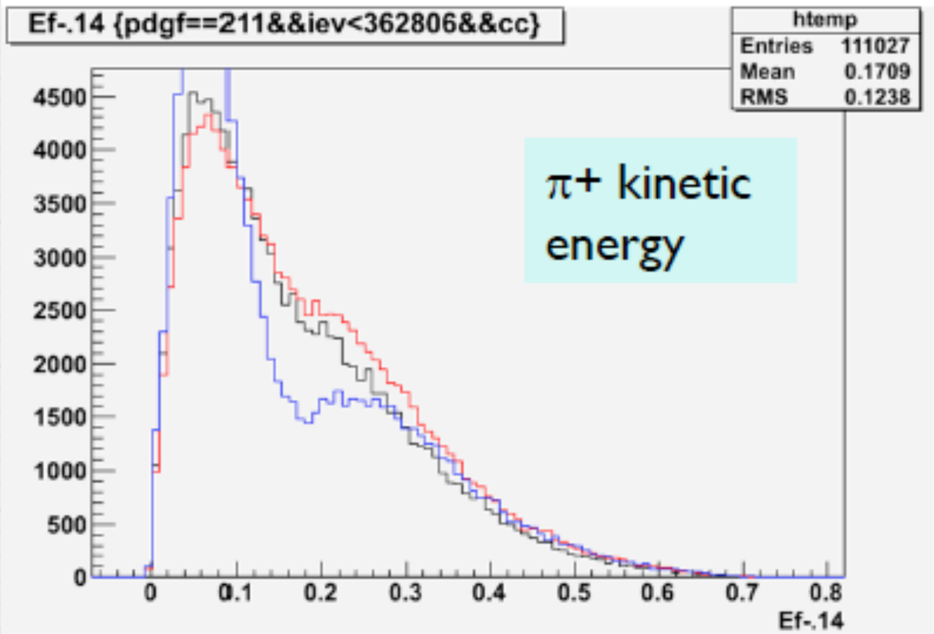
S. Dytman
NuINT 2011

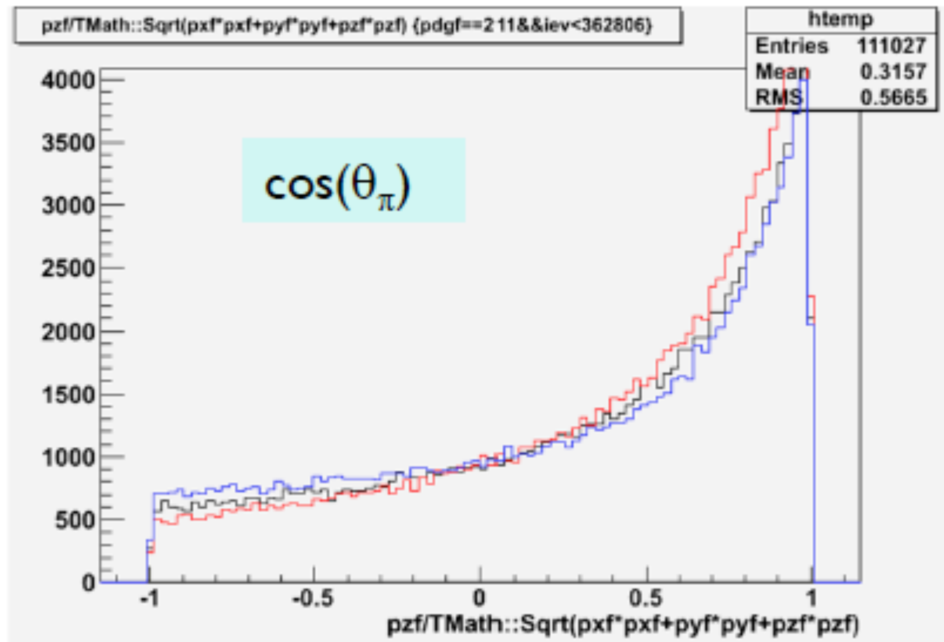
- Codes are Intranuclear Cascade (INC), real and inspired.
- hN is straightforward INC
  - Uses free 2- and 3-particle free cross sections + Fermi motion
  - Success comes from importance of quasielastic reaction mechanism in nuclear physics *and* existence of PWA data.
- hA is simplified INC
  - Construct models of full chain of events
  - Uses simple representations of hN code, data, and intuition.
  - Easily reweighted
  - New version has
    - better π^+:π^-,
    - better angle/energy distributions for inelastic scattering/absorption
    - Better n/p distributions.

Pion energy, angle

S. Dytman
NuINT 2011

- Same legend for all cases
  - Old hA (black), new hA (red), hN (blue)
- Total of 111k pions in 263k events





Cross Section

Hugh Gallagher
Nova Collab Mtg.
Apr. 19, 2012

Overall cross section model in GENIE has not been changed in over five years. Identical to the model used by MINOS (in neugen3).

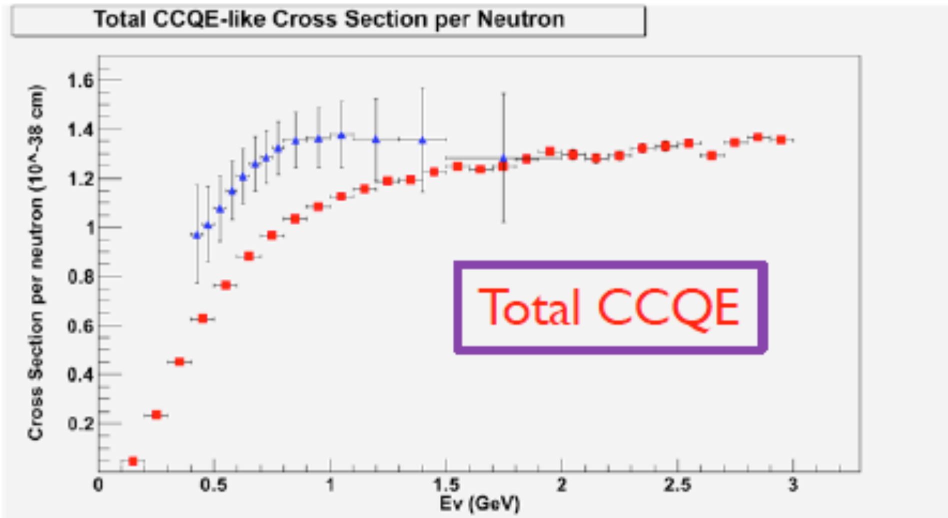
A lot of high-quality data, in particular of differential distributions, has become available since then from MiniBooNE and others.

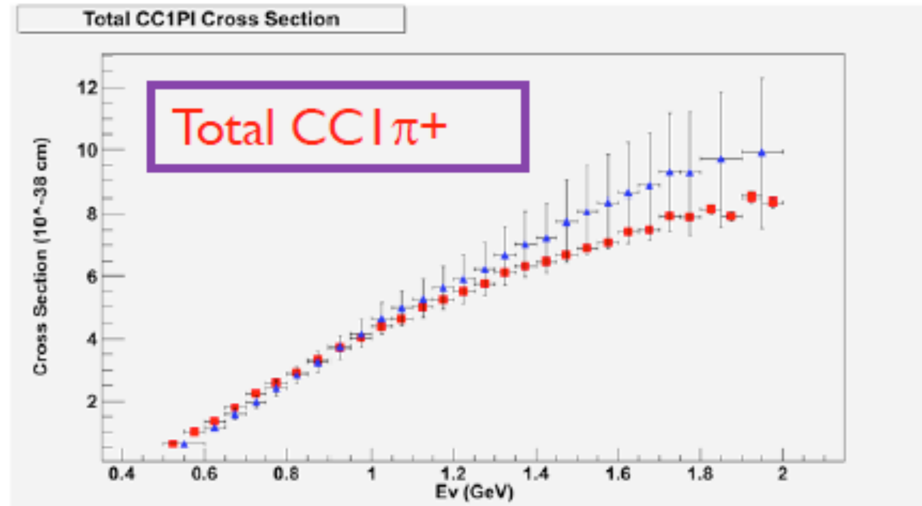
An effort is underway for this summer to retune the GENIE cross section model.

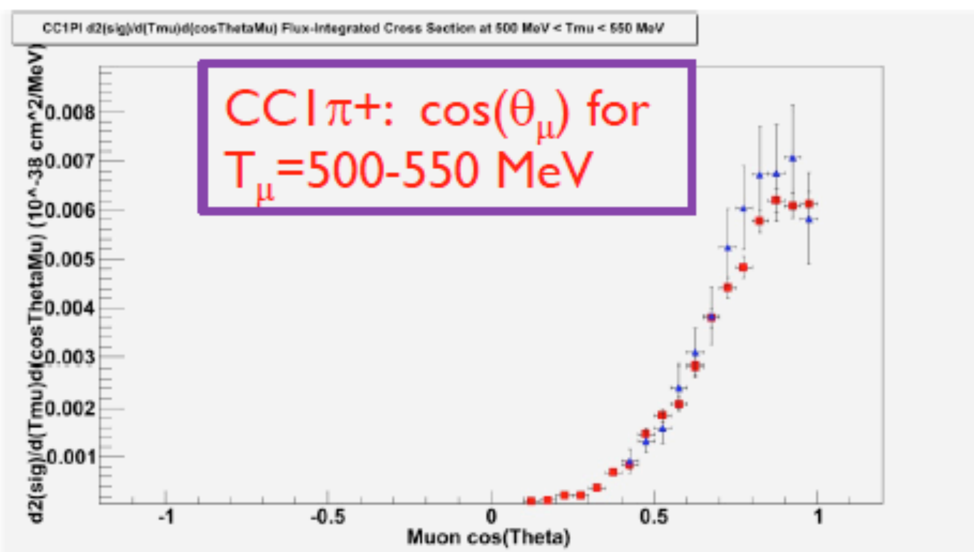
Requires updating many validation programs and data collections. Effort being led to Costas Andreopoulos and T2K colleagues.

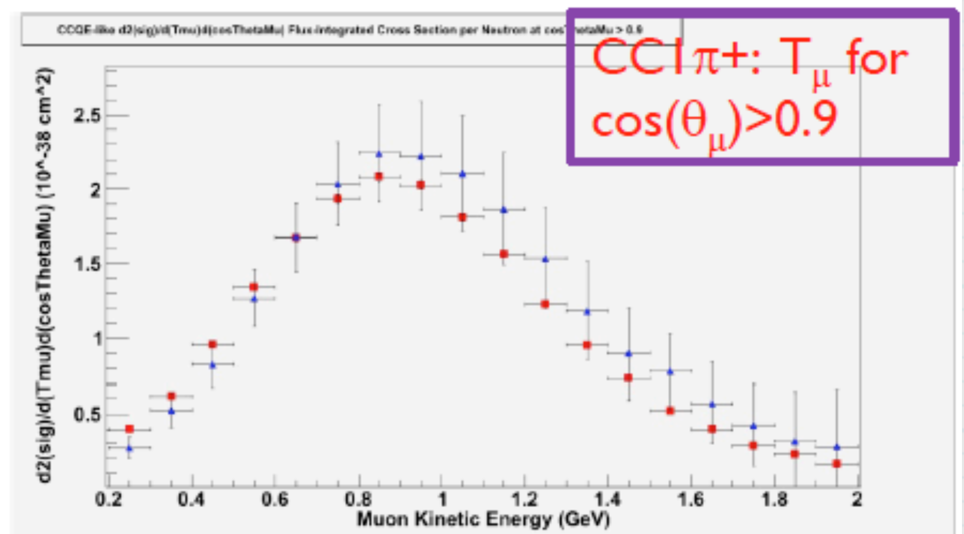
Modern validation - MiniBoone (detailed exam of CCQE and CC1π+) [no tuning]

S. Dytman





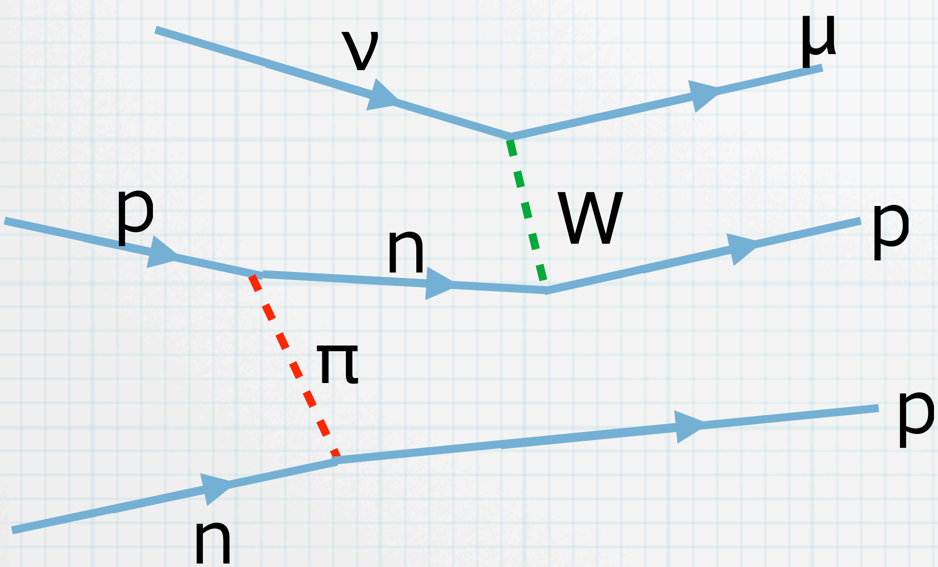


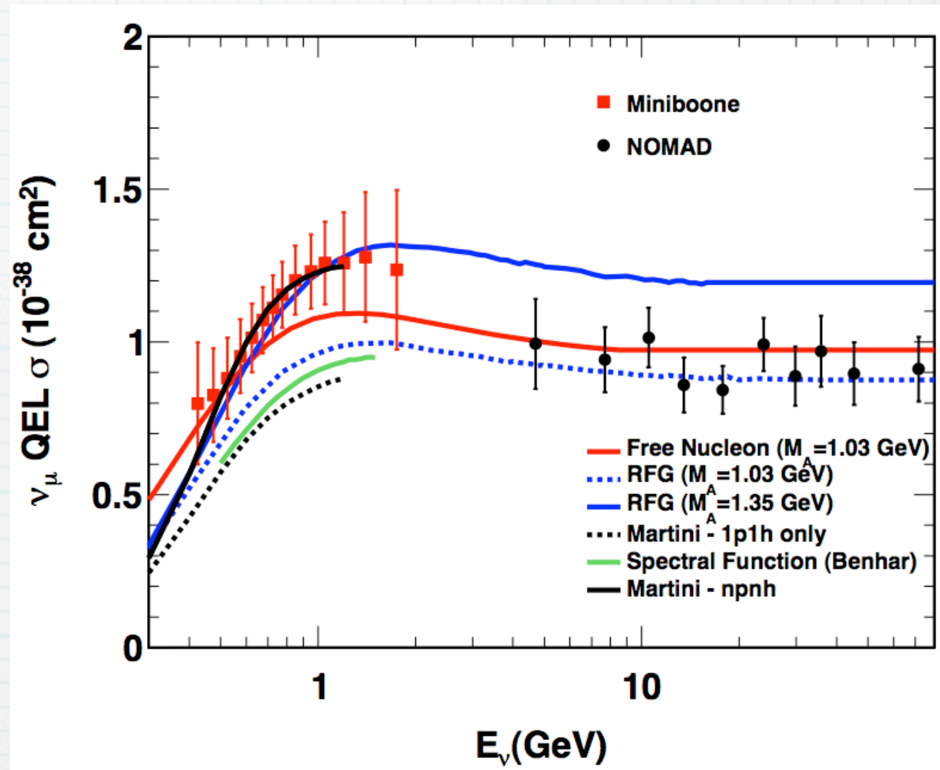


np-nh processes

Hugh Gallagher
Nova Collab Mtg.
Apr. 19, 2012

In neutrino-nucleus scattering there are processes which do not occur on free nucleons! n-body currents.





Scattering off a quasi-deuteron inside the nucleus is a possibility. Many such diagrams, with n nucleons in the initial and final states.

np-nh modelling

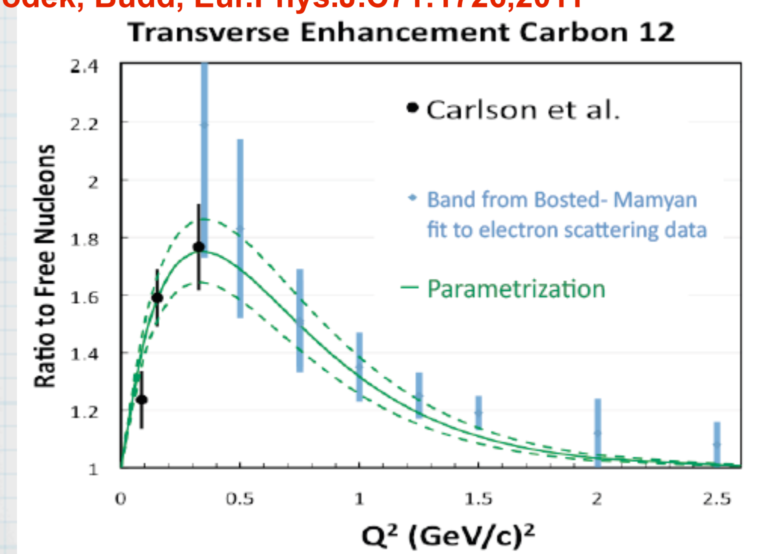
Hugh Gallagher
Nova Collab Mtg.
Apr. 19, 2012

Theoretical calculations are quite complicated. Have focussed on leptonic distributions and total cross sections, no attempts to calculate details of hadronic observables.

For GENIE modeling:

- Incorporate a model for prediction of leptonic variables.
- Develop a reasonable model for production of hadronic final state from specified 4-momentum transfer (e.g. Sobczyk, arXiv:1201.3673).
- Incorporate enough flexibility to be able to evaluate different assumptions and evaluate systematic errors.

Bodek, Budd, Eur.Phys.J.C71:1726,2011



Bodek, Budd, Eur.Phys.J.C71:1726,2011

5.2 The "Transverse Enhancement" model

We use our parametrization of $\mathcal{R}_T$ to modify G_{Mp} and G_{Mn} for bound nucleons as follows. First, we assume that the enhancement in the transverse QE cross section modifies $\mathcal{G}_M^V = G_{Mp} - G_{Mn}$ for nucleons bound in carbon with a form given by

$$G_{Mp}^{nuclear}(Q^2) = G_{Mp}(Q^2) \times \sqrt{1 + AQ^2 e^{-Q^2/B}}$$
$$G_{Mn}^{nuclear}(Q^2) = G_{Mn}(Q^2) \times \sqrt{1 + AQ^2 e^{-Q^2/B}}.$$

In all of the studies we keep $G_{Ep}(Q^2)$, $G_{En}(Q^2)$ and $F_A(Q^2)$ for bound nucleons the same as for free nucleons. The

Knobs for Hadronic System Modeling

H. Gallagher
Mar. 27, 2012
GENIE MEC modeling mtg

Sensitivity of a particular detector to these processes can depend critically on the modeling of the hadronic system.

Experiments would like to be able to evaluate a broad range of model assumptions.

Would like to make models reweightable.

- Evaluate different models (or assumptions) with a single fully simulated/reconstructed MC sample.
- Improve simple models to incorporate new theory input as it becomes available.

One such example model:

1) Select $q = (\nu \equiv E_\nu - E_l, \vec{q})$ from cross section model

2) Select $\vec{p}_i$ for the i=1,2 nucleons from a Fermi gas distribution, nucleons are on-shell.

3) Hadronic system is $p_{had} = q + p_1 + p_2$

4) Phase space decay of hadronic system above into two nucleon final state.

Knobs for Hadronic System Modeling

H. Gallagher
Mar. 27, 2012
GENIE MEC modeling mtg

Friendly amendments:

1) Include an overall 'removal energy', E_B, similar to the Impulse Approximation.

$q = (\nu, \vec{q})$ at the leptonic vertex

$\tilde{q} = (\nu - E_B, \vec{q})$ at the hadronic vertex

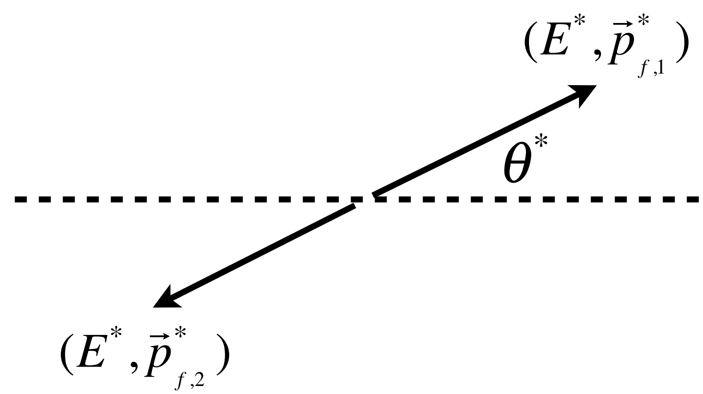
E_B is energy lost to the nuclear environment in removing this correlated pair.

E_B could be chosen as follows:
  1/2 of events have $E_B=0$
  1/2 of events have E_B selected uniformly from $(0, \nu)$

2) Include probability distribution to control 'sharing' of 4-momentum transfer by nucleons:

$$p_{had} = \tilde{q} + p_1 + p_2$$

$$p_{had}^2 = W^2 = 4E^{*2}$$



Add knob in GENIE to select cm angle from a pdf (Gaussian+quadratic). Current model is isotropic in c.m.s.

BACKUP

Hugh Gallagher
Nova Collab Mtg.
Apr. 19, 2012

Models

Hugh Gallagher
Nova Collab Mtg.
Apr. 19, 2012

Things I took away from the Maltini talk:

Magnitude of the effect is large (40% for miniBoone!).

Relative role of 2p-2h is smaller for antineutrinos than in neutrino scattering.

Relative contribution of 2p-2h is the same for all nuclei to order 10-20%.

Since initial state in 2p-2h is dominantly quasi-deuteron final state is largely:
- neutrinos: muon + 2 protons
- anti-nu: muon + 2 neutrons

MiniBooNE flux integrated
CC total cross section

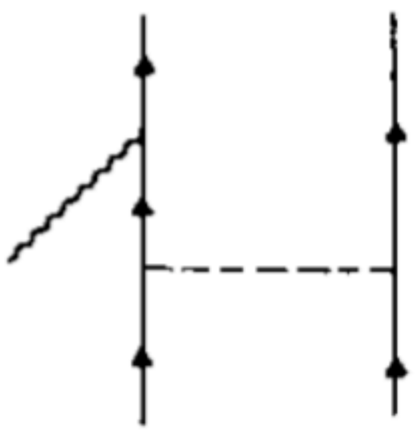
	Neutrino			Antineutrino		
	QE	np-nh	QE+np-nh	QE	np-nh	QE+np-nh
bare	7.46	2.77	10.23	2.09	0.52	2.61
RPA	6.40	2.73	9.13	1.60	0.47	2.07

In units of 10^{-39} cm^2

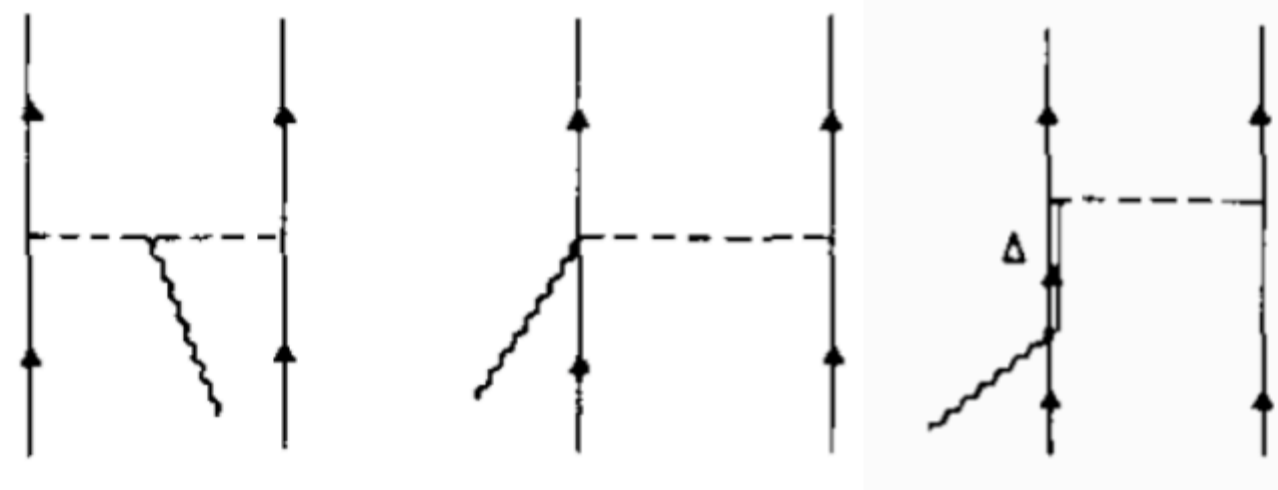
Some diagrams for 2 body currents

Maltini Seminar FNAL Sep 30, 2010.

Nucleon-Nucleon correlations



Meson Exchange Currents (MEC)



Pion in flight (only for vector)

Contact

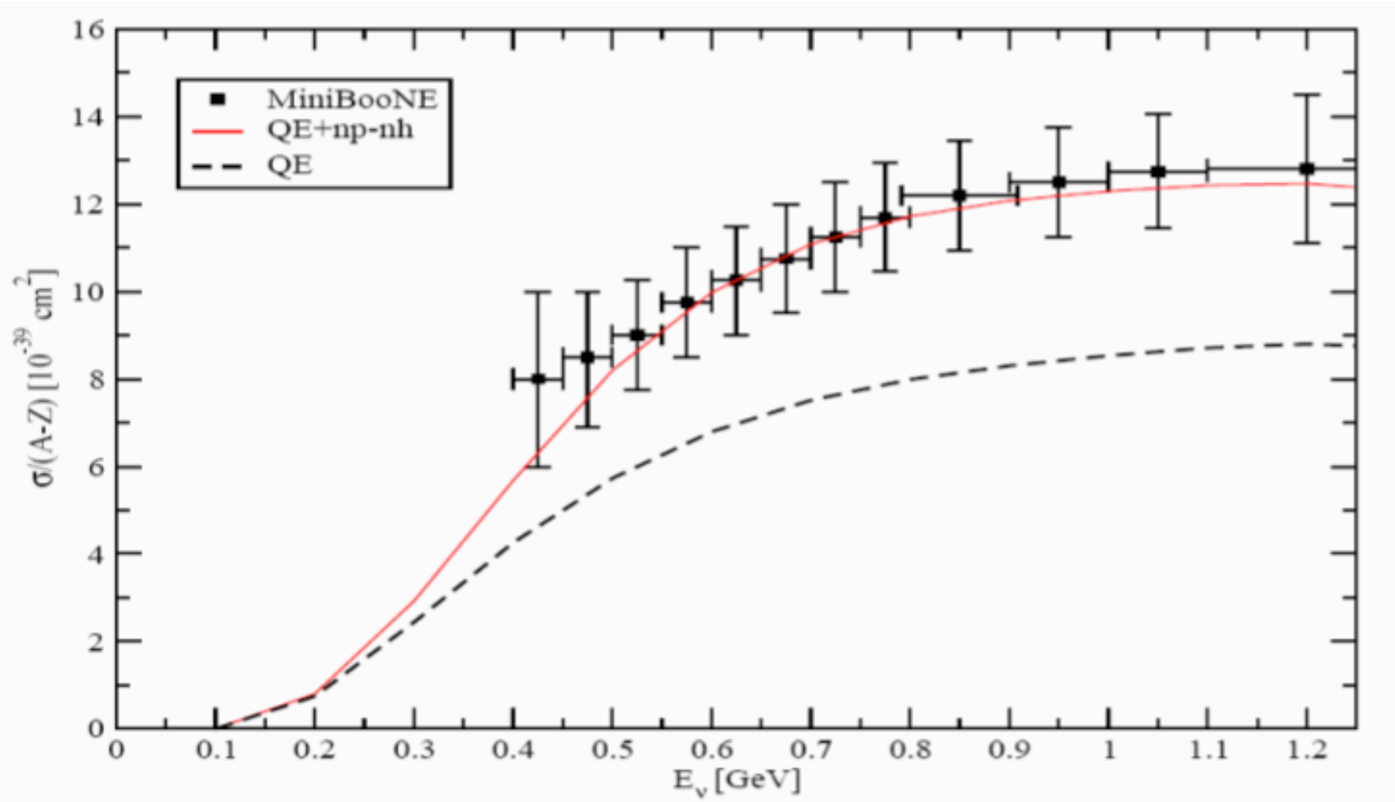
Delta

$\underbrace{\hspace{3em}}$ Destructive interference

Neutrino Bottom Line

Hugh Gallagher
Nova Collab Mtg.
Apr. 19, 2012

Maltini Seminar FNAL Sep 30, 2010.



Flux averaged:

MiniBooNE

9.4 $10^{-39} cm^2 \pm 11\%$

Our model
QE+np-nh (CCQE-like)
9.1 10^{-39} cm^2

Our model
genuine CCQE
6.4 10^{-39} cm^2

M. Martini, M. Ericson, G. Chanfray, J. Marteau Phys. Rev. C 80 065501 (2009)

Agreement with MiniBooNE without increasing M_A

Electron Scattering

Hugh Gallagher
Nova Collab Mtg.
Apr. 19, 2012

The main reason to believe that such contributions exist and can be potentially large comes from looking at electron scattering.

There are certain kinematic regions (“the dip”) where no single-particle scattering model comes close to the data.

The plot at right, and much of the information on the following slides, is from M. Maltini’s (+Magda Ericson) Fermilab Neutrino PPD talk from yesterday.

In it he presents predictions from a specific model:
Phys. Rev. C 80 065501 (2009)
Phys. Rev. C 81 045502 (2010)

Maltini Seminar
FNAL Sep 30, 2010.